FINAL REPORT

Title: Restoration experiments in ponderosa pine at Fort Valley Experimental Forest: Twenty years post-fire

JFSP PROJECT ID: 15-1-07-1

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PI Name **Margaret M. Moore**
Affiliation **School of Forestry, Northern Arizona University, Flagstaff, AZ**

PI2 Name **David W. Huffman**
Affiliation **Ecological Restoration Institute, Northern Arizona University, Flagstaff, AZ**

PI3 Name **Peter Z. Fulé**
Affiliation **School of Forestry, Northern Arizona University, Flagstaff, AZ**

PI4 Name **Robert T. Strahan**
Affiliation **Lomakatsi Restoration Project, Ashland, OR**

PI5 Name **Andrew J. Sánchez Meador**
Affiliation **Ecological Restoration Institute, Northern Arizona University, Flagstaff, AZ**

PI6 Name **W. Keith Moser**
Affiliation **US Forest Service, Rocky Mountain Research Station, Flagstaff, AZ**

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Project Title:

Restoration experiments in ponderosa pine at Fort Valley Experimental Forest: Twenty years post-fire

Project Numbers:
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Principal Investigator Name(s) and Affiliation(s):
Margaret M. Moore[1], David W. Huffman[2], Peter Z. Fulé[1], Robert T. Strahan[3], Andrew J. Sánchez Meador[1,2], and W. Keith Moser[4]
[1]School of Forestry, Northern Arizona University, Flagstaff, AZ
[2]Ecological Restoration Institute, Northern Arizona University, Flagstaff, AZ
[3]Lomakatsi Restoration Project, Ashland, OR
[4]US Forest Service, Rocky Mountain Research Station, Flagstaff, AZ

Final Report (*Updated*):
August 17, 2015 through September 30, 2019; and **UPDATED September 2, 2021 with database and metadata,** which is now published on US Forest Service Research Data Archives.

Project Abstract/Summary:
This project, which was funded by the Joint Fire Science Program (JFSP), measured the 20+-year post-fire response of vegetation and fuels on a restoration experiment in a ponderosa pine-bunchgrass ecosystem on the Fort Valley Experimental Forest (FVEF) near Flagstaff, AZ. In 1992, this replicated experiment was established within an old-growth ponderosa pine forest to evaluate the long-term ecosystem responses of an untreated control and two restoration treatments, which were thinning from below and thinning from below with prescribed burning. Specifically, we quantified changes in key response variables related to post-fire fuels and plant succession in southwestern ponderosa pine, such as pre- and post-settlement tree structure, understory herbaceous cover and diversity, and surface fuels. We examined the interaction of prescribed fire and drought on tree growth and mortality, herbaceous abundance and diversity over this 20+-year period. Results from this research resulted in 10 oral or poster presentations at regional and national meetings (such as the Fire Continuum Conference 2018), and six manuscripts published in refereed journals. This experimental site continues to be used for many information and education programs. We gave 15 field trips or workshops to local, regional and national groups over the study period (including National Silviculture Workshop, Society of American Foresters Silviculture Instructors' Field Tour, Western Mensurationists Annual Meeting; and field tour to the Science and Application of Landscape Ecology to National Forest Management workshop). We highlight specific accomplishments and some results below. These long-term data (1992-2019) of overstory tree, herbaceous, fuels, and repeat photographs are published on the US Forest Service Research Data Archive repository. Finally, the results from this experiment continues to provide useful guidelines to larger (landscape-scale) ponderosa pine restoration and fuels management projects throughout the Southwest and Rocky Mountain regions.

Specific Accomplishments by Objective:
Detailed accomplishments by objective during the 4-year reporting period are listed below (August 2015 through September 2019; **UPDATED September 2, 2021** for database/metadata). Our overall objectives for this 4-year study were to: 1) Remeasure: a) tree structure, b) herbaceous vegetation production and diversity, and c) fuel load responses in all treatments in fall 2016, and examine long-term responses of overstory trees, herbaceous, and surface fuels to treatments, climate, and treatment-climate interactions. 2) Other accomplishments included : a) continue the prescribed burn treatment, b) record sub-meter locations of study site boundaries, plots and subplots, c) study site fence maintenance, d) creation of field computer data collection forms, and e) repeat photographs. 3) Continue to use this site for information and education programs and field trips; and 4) Enter long-term (20+ years) overstory tree, herbaceous, fuels, and repeat photographs into US Forest Service Research Data Archive repository.

Objective 1) Remeasure tree structure, herbaceous vegetation production and diversity, and fuel loads by treatment in 2016 and over time (1992-2019).

1a) Tree structure and preliminary results. During fall 2016, we collected tree size and condition class and extracted tree cores for all trees (≥ 2.54 cm DBH) in the two treated areas (thin only and thin plus prescribed burn), plus we collected a subset (2.5% random sample) of tree sizes and cores in the control treatment. All trees remeasured in 2016 were retagged. All data were recorded electronically (on field computers) and entered in a MS Access database. Tree size structure were summarized for each treatment, expanded to a per area basis, and tested for statistical significance among treatments.

A total of 627 cores were extracted. It is worth noting that we attempted to collect cores from the same trees sampled in 2006 (10 years earlier), but due to overstory mortality of 59 trees, we collected 627 cores (instead of the 686 cores originally collected in 2006). These tree cores were taken to the NAU ERI lab, mounted and sanded, cross-dated and tree ring widths measured to relate tree growth as a function of restoration treatment and weather over the past 20 years.

In general, from 1992-2017, the restoration treatments (thin only and thin plus burn) reduced basal area by approximately half, retained presettlement trees, and removed most small trees. Preliminary long-term results indicate that net stand basal area growth was about 10% per decade following treatment and was slightly higher in the thin-only treatment. Net basal area loss in the control was approximately 15% per decade. Individual tree growth patterns showed large decreases (as much as 7-times) in annual basal area increment (BAI) due to four exceptional droughts that occurred during the 20-25-year study, and higher resilience to drought was observed in both restoration treatments as compared to the control (Sánchez Meador et al., 2016, 2017, and 2018).

These climate-treatment tree growth interactions over the past 20+ years were presented at four regional and national meetings between 2017 and 2018 (Fulé et al., 2017a and b; Sánchez Meador et al., 2016, 2017, and 2018), and **one manuscript submitted to *Ecological Applications*, which is a synthesis of these results (Fulé, P. Z. et al. 2021)**.

1b) Herbaceous production & diversity and results. We measured herbaceous plant cover, composition and species richness (two, 1-m^2 quadrats per subplot; n=110) by treatment and patch type (presettlement or old-growth tree group, remnant grass opening, etc.) between 1992 and 2019. **UPDATE:** We collected herbaceous plant cover and species richness in fall 2020, and we will collect those data again in September 2021.

We measured herbaceous plant production (biomass; clipped and weighed) by species every four years (1992, 1993-1996, 1998, 2002, 2006, 2010, 2014, 2018). **UPDATE:** We plan to measure herbaceous biomass again in fall 2022 prior to the 2022 prescribed burn.

Herbaceous biomass responded positively to both restoration treatments. Prior to treatment remnant grass openings had significantly higher herbaceous biomass (~8 times higher) than all other patch types (<100 kg ha^{-1}). Species richness increased and became similar to remnant openings in the thinning plus burning treatments, and treatment, time, and treatment-by-time interaction effects explained 45% of the variation in species richness.

Predicting restoration outcomes requires an understanding of the natural variability of ecosystem properties. A hierarchy of predictability has been proposed that ranks measures of restoration success from most-to-least predictable in the following order: vegetation structure > taxonomic diversity > functional diversity > taxonomic composition. Laughlin et al. 2017 tested the hierarchy of predictability on the overstory and understory data results from this ponderosa pine restoration experiment. They used linear mixed effects models to analyze changes in herbaceous biomass, species richness, two functional diversity (FD) indices, community- weighted mean (CWM) traits and taxonomic composition among experimental restoration treatments from 1992 to 2014. Restoration treatments included combinations of light or heavy tree thinning and no fire or repeated prescribed fire every 4 years to release the herbaceous understory from overstory tree competition. Herbaceous biomass and species richness were the two most predictable and least variable measures of restoration treatment success, whereas taxonomic composition exhibited the highest variability among plots through time.

1c) Surface fuel loads and preliminary results. We measure surface fuel loads (two Brown's transects per subplot; n=110) between 1992 and 2019. We analyzed surface fuel loads in 2016, two years after the 2014 prescribed burn. Surface fuel loads differed among treatments and heterogeneity in tree spatial patterns increased following restoration treatments (Sánchez Meador et al., 2018). **UPDATE:** We collected surface fuel loads in fall 2020 and we plan to collect surface fuel loads again in September 2021.

1d) Other – carbon dynamics. One additional aspect of this study is the carbon dynamics. During the summer and fall 2018, we separated pine needle and herbaceous samples (one graminoid and one legume) from 1998, 2004, and 2018 and conducted C:N analyses (USFS RMRS Soil Lab; S. Overby) to compare net primary production (NPP) among restoration treatments at this study site.

Objective 2) Other accomplishments include: a) continue the prescribed burn treatment, b) record sub-meter locations of study site boundaries, plots and subplots, c) study site fence maintenance, d) creation of field computer data collection forms, and e) repeat photographs.

2a) Continue the long-term prescribed burn treatment. In cooperation with the US Forest Service Coconino National Forest and Rocky Mountain Experiment Station, the first prescribed burn occurred at the study site in October 1994 and subsequent burns occurred in October 1998, 2002, 2006, 2010, 2014 and fall, 2018. **UPDATE:** We plan another prescribed burn for this site in fall 2022.

2b) Record locations boundaries, plots and subplot centers. We remarked and obtained sub-meter UTM coordinates for treatment (plot) boundaries and subplot centers (n=55 subplots; 110 quadrats and 110 transects) in fall 2015 and 2016.

2c) Study site fence maintenance. The elk fence surrounding the study site was repaired and electrified in the fall 2015 and 2016.

2d) Field computer data collection forms. We created database forms for data collection (tree, herbaceous, and fuels) on Panasonic Toughbook field computers during fall 2016.

2e) Repeat photographs. We took permanent repeat photographs at subplot centers in fall 2015, 2016, 2017, 2018, and 2019. Now we have a long-term repeat photographic record of these experimental treatments from 1992-2019. **UPDATE:** We collected repeat photographs in the fall 2020, and we will collect those repeat photographs again in fall 2021.

Objective 3) Education and field trips. This experimental site continues to be used for many information and education programs. We gave 15 field trips or workshops to local, regional and national groups over the study period (including National Silviculture Workshop, Society of American Foresters Silviculture Instructors' Field Tour, Western Mensurationists Annual Meeting, etc.). We list specific field trips, workshops, etc. and a local radio station feature (KNAU) in the deliverables section below.

Objective 4) Upload long-term data to US Forest Service Research Data Archive repository. We continued to clean up the 20+-year old database (e.g., checking for consistency and errors, deleting old queries, etc.) and updated the spatial locations of ingrowth, etc. **UPDATE:** The long-term data from this experiment (overstory tree, understory herbaceous, fuels and repeat photographs) has been uploaded and published on the US Forest Service Research Data Archive repository (September, 2021; Moore et al. 2021) https://www.fs.usda.gov/rds/archive/

Moore, Margaret M.; Huffman, David W.; Fulé, Peter Z.; Sánchez Meador, Andrew J.; Covington, William W.; Roccaforte, John P.; Springer, Judy D.; Stoddard, Michael T.; Normandin, Donald P., Curran, Scott; Laughlin, Daniel C.; Strahan, Robert T.; Moser, W. Keith. 2021. Fort Valley Experimental Forest G. A. Pearson Natural Area forest restoration site: tree

overstory, herbaceous understory, fuels, and repeat photographs database. ***Fort Collins, CO: Forest Service Research Data Archive.*** https://doi.org/10.2737/RDS-2021-0079

Deliverables:

Contact information and deliverables (manuscripts, presentations, field tours, radio station feature, workshops and metadata) during the 4-year reporting period (August 2015-September 2019; and August and September 2021) are listed in Appendix A, B and C below.

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Appendix A: Contact Information for Key Personnel

Margaret M. Moore, School of Forestry, Northern Arizona University, Flagstaff AZ 86011
Margaret.Moore@nau.edu

David W. Huffman, Ecological Restoration Institute, Northern Arizona University, Flagstaff AZ 86011
David.Huffman@nau.edu

Peter Z. Fulé, School of Forestry, Northern Arizona University, Flagstaff AZ 86011
Pete.Fule@nau.edu

Robert T. Strahan, Lomakatsi Restoration Project, Ashland OR 97520
Rob@Lomakatsi.org

Andrew J. Sánchez Meador, Ecological Restoration Institute, Northern Arizona University, Flagstaff AZ 86011
Andrew.SanchezMeador@nau.edu

W. Keith Moser, Research Forester and Scientist-in-Charge at Fort Valley Experimental Forest, US Forest Service, Rocky Mountain Research Station, Flagstaff, AZ
Warren.K.Moser@usda.gov

Appendix B. List of Peer-Reviewed Journal Articles, Conference Oral and Poster Presentations, Field Tours, Radio Feature, and Workshops

1) Peer-reviewed publications and metadata (n=7):

Laughlin, D. C., R. T. Strahan, M. M. Moore, P. Z. Fulé, D. W. Huffman and W. W. Covington. 2017. The hierarchy of predictability in ecological restoration: are vegetation structure and functional diversity more predictable than community composition? ***Journal of Applied Ecology*** 54:1058-1069.

Rodman, K. C., A. J. Sánchez Meador, M. M. Moore and D. W. Huffman. 2017. Reference conditions are influenced by the physical template and vary by forest type: A synthesis of *Pinus ponderosa*-dominated sites in the southwestern United States. ***Forest Ecology and Management*** 404:316–329.

Laughlin, D. C., R. T. Strahan, P. B. Adler, and M. M. Moore. 2018. Survival rates indicate that correlations between community weighted mean traits and environments can be unreliable estimates of the adaptive value of traits. ***Ecology Letters*** 21:411–421.

Strahan, R.T., D.C. Laughlin, and M.M Moore. 2018. An experimental test of the Community Assembly by Trait Selection (CATS) model. ***PLoS ONE*** 13(11): e0206787. doi.org/10.1371/journal.pone.0206787

Puhlick, J. J., D. C. Laughlin, M. M. Moore, C. H. Sieg, S. T. Overby, and J. D. Shaw. 2021. Soil properties and climate drive ponderosa pine seedling presence in the southwestern USA. ***Forest Ecology and Management*** 486: https://doi.org/10.1016/j.foreco.2021.118972

Fulé, P. Z., A. J. Sánchez Meador, Andrew; M. M. Moore, W. W. Covington, T. E. Kolb, D. W. Huffman, D. P. Normandin, and J. P. Roccaforte. 2021. Forest restoration treatments improve survival and growth of ponderosa pines in severe drought. ***Ecological Applications*** *(submitted August 2021).*

Moore, Margaret M.; Huffman, David W.; Fulé, Peter Z.; Sánchez Meador, Andrew J.; Covington, William W.; Roccaforte, John P.; Springer, Judy D.; Stoddard, Michael T.; Normandin, Donald P., Curran, Scott; Laughlin, Daniel C.; Strahan, Robert T.; Moser, W. Keith. 2021. Fort Valley Experimental Forest G. A. Pearson Natural Area forest restoration site: tree overstory, herbaceous understory, fuels, and repeat photographs database. Fort Collins, CO: ***Forest Service Research Data Archive***. *https://doi.org/10.2737/RDS-2021-0079*

2) Conference Presentations (oral and poster presentations; n=10):

Sánchez Meador, A. J. 2016. Restoration of southwestern frequent fire forests: How did we get here and where are we going? Invited Oral Presentation, New Mexico Forest and Watershed Restoration Institute's Sacramento Mountains Desired Conditions Field Tour and Workshop. October 25-28, 2016, Ruidoso, NM.

Sánchez Meador, A. J., M. M. Moore, R. T. Strahan, D. W. Huffman, P. Z. Fulé, W. W. Covington, and W. K. Moser. 2016. Vegetation dynamics of a 20-year ecological restoration

experiment, Fort Valley Experimental Forest, Arizona. Oral Presentation and Proceedings, Society of American Foresters, National Convention. November 2-6, 2016, Madison, WI.

Fulé, P. Z., A. J., Sánchez Meador, D. P. Normandin, D. W. Huffman, M. M. Moore, W. K. Moser, W. W. Covington, and R. T. Strahan. 2017a. Ponderosa pine growth responses to climate and restoration treatments at Fort Valley Experimental Forest, Flagstaff, AZ. Oral Presentation at the 14th Biennial Conference of Science & Management on the Colorado Plateau & Southwest Region, September 11-14, 2017, Flagstaff, AZ.

Fulé, P.Z., A. J. Sánchez Meador, D.P. Normandin, D.W. Huffman, M.M. Moore, W.K. Moser, W.W. Covington, and R.T. Strahan. 2017b. Ponderosa pine growth responses to climate and restoration treatments at Fort Valley Experimental Forest, Flagstaff, AZ. Society of American Foresters Annual Convention, November 17, 2017, Albuquerque, NM.

Puhlick, J. J., D. C. Laughlin, M. M. Moore (presenter), C. H. Sieg, S. T. Overby, and J. D. Shaw. 2017. A refined regional model for predicting southwestern ponderosa pine regeneration densities. Poster presentation, Society of American Foresters Annual Convention, November 17, 2017, Albuquerque, NM.

Fulé, P.Z. 2017. Southwestern forests: past, present, and future. Presentation to the Silviculture Instructors' Tour for the Society of American Foresters Annual Convention, November 12, 2017, Flagstaff, AZ.

Sánchez Meador, A. J. 2017. Using Historical Range of Variability to inform future management strategies. Invited Oral Presentation and Proceedings, 67th Western Forest Insect Work Conference. May 1-5, 2017, Jackson, WY.

Sánchez Meador, A. J., M. M. Moore, P. Z. Fulé, D. W. Huffman, D. C. Laughlin, R. T. Strahan, D. P. Normandin, W. K. Moser, and W. W. Covington. 2018. Twenty-five years of ecological restoration research at the G. A. Pearson Natural Area, Fort Valley Experimental Forest, Arizona. Oral Presentation at the Fire Continuum Conference, May 21-24, 2018, Missoula, MT.

Sánchez Meador, A.J. Twenty-five years of ecological restoration research at the G.A. Pearson Natural Area. 2018. Oral presentation to the NAU Biology Department, March 30, 2018, Flagstaff, AZ.

Moore, M. M., D. C. Laughlin, R. T. Strahan, J. D. Bakker, H. E. Dowling, J. D. Springer and S. D. Olberding. 2019. One hundred years of range research in northern Arizona's ponderosa pine-bunchgrass ecosystems. Oral Presentation at the 15th Biennial Conference of Science & Management on the Colorado Plateau & Southwest Region, September, 2019, Flagstaff, AZ.

3) Field tours to FVEF restoration experimental/demonstration site (n=15):
More than 15 field tours to the FVEF restoration site included:
a) Walter Dunn, Southwest Ecological Restoration Institutes (SWERI) Program Manager, USFS R3, *April 21, 2016*;
b) Dr. Steven Archer, University of Arizona, *May 5, 2016*;

c) Eric Hoening (USFS International Program) and Riri Fithriadi (USFS IP- Indonesia Program coordinator) were given a tour of the experiment/demonstration area with Larry Fisher (University of Arizona) and Yeon-Su Kim (NAU), *April 20, 2016*;
d) National Silviculture Workshop Field Tour, 2017. Field tour to Fort Valley Experimental Forest and restoration/demonstration site by W. W. Covington and W. K. Moser, *July 19, 2017*;
e) Moore, M. M. and W. K. Moser. 2017. Society of American Foresters Silviculture Instructors' Field Tour of Fort Valley Experimental Forest and restoration/ demonstration site. Society of American Foresters Annual Convention, *November 13, 2017*;
f) Sánchez Meador, A. J. 2018. Western Mensurationists' Meeting Field Tour of Fort Valley Experimental Forest and restoration/demonstration site. Western Mensurationists Annual Meeting, *June 17, 2018*;
g) Sánchez Meador, A. J. et al. 2018. Field tour of Fort Valley Experimental Forest and restoration/demonstration site. As part of short course by K. McGarigal and S. Cushman entitled "Science and Application of Landscape Ecology to National Forest Management" for the USDA Forest Service, *January 2018 and February 2019*, Flagstaff, AZ;
h) Flagstaff Festival of Science, Tours of FVEF restoration and demonstration site. Fort Valley Experimental Station, *September*, ***2016, 2017, 2018, 2019***;
i) Northern Arizona University, School of Forestry, Forestry Juniors field trip (forest ecology and silviculture), Fall ***2016, 2017, 2018, 2019***.

4) KNAU Radio Station Feature and Interview. 2019. "At century-old experimental forest, history is in the trees." https://www.knau.org/post/century-old-experimental-forest-history-trees - April 2019. Featured long-term forest restoration treatments at Fort Valley Experimental Forest by Northern Arizona University, Ecological Restoration Institute and School of Forestry.

5) Workshops (n=1):
2017 National Silviculture Workshop, Flagstaff, AZ. W. K. Moser, USFS RMRS host and sponsor, *July 18-20, 2017*.

Appendix C. Metadata Data Archive Publication (n=1):

The long-term data from this experiment (overstory tree, understory herbaceous, fuels and repeat photographs) has been uploaded to the US Forest Service Research Data Archive repository (September 2021; Moore et al. 2021)
https://www.fs.usda.gov/rds/archive/

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